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Dynamic Tests Of Short Sections Of Corrugated Metal Beam Guardrail Series XIII

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**16. ABSTRACT**
The results of eight full scale vehicle impact tests into short sections (less than 100 ft) of 27-in. high blocked-out corrugated metal beam guardrail are reported.

Two tests were performed on free standing unanchored short sections, three tests on free standing sections using two different end anchorage systems and three tests on simulated bridge approach guardrail flares using a cable anchor assembly on the upstream or approach end and rigid attachment to the concrete bridge rail parapet at the other end. The tests were conducted at speeds ranging from 56 to 63 mph and approach angles varying from 24 to 33 degrees utilizing 1964 to 1966 sedans weighing approximately 4500 lbs.

The first two tests (131 and 132) proved that short, free standing unanchored guardrail sections up to 62.5 ft in length are ineffective under severe impact loading conditions (approximately 60 mph/25 deg). This in turn indicates that any unanchored guardrail section, regardless of length, is vulnerable when struck within 30 ft. of either end.

The results of Tests 133 and 134 indicate that short guardrail sections with sloping rail anchorage ("Texas Twist") are structurally adequate when struck in the center (full height section), but performance is questionable with regard to impacts into the ramped ends.

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Interim Report
M & R No. 636392-4
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Mr. J. A. Legarra
State Highway Engineer

Dear Sir:

Submitted herewith is a research report entitled:

DYNAMIC TESTS OF SHORT SECTIONS OF

CORRUGATED METAL BEAM GUARDRAIL

SERIES XIII

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Principal Investigator

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Very truly yours,

JOHN L. BEATON
Materials and Research Engineer

68-04

ABSTRACT

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Two tests were performed on free standing unanchored short sections, three tests on free standing sections using two different end anchorage systems and three tests on simulated bridge approach guardrail flares using a cable anchor assembly on the upstream or approach end and rigid attachment to the concrete bridge rail parapet at the other end. The tests were conducted at speeds ranging from 56 to 63 mph and approach angles varying from 24 to 33 degrees utilizing 1964 to 1966 sedans weighing approximately 4500 lbs.

The first two tests (131 and 132) proved that short, free standing unanchored guardrail sections up to 62.5 ft in length are ineffective under severe impact loading conditions (approximately 60 mph/25 deg). This in turn indicates that any unanchored guardrail section, regardless of length, is vulnerable when struck within 30 ft of either end.

The results of Tests 133 and 134 indicate that short guardrail sections with sloping rail anchorage ("Texas Twist") are structurally adequate when struck in the center (full height section), but performance is questionable with regard to impacts into the ramped ends.

As a result of Tests 135 through 138, an effective cable anchoring device for short free standing sections of guardrail was developed. In addition, an efficient bridge approach guardrail flare design was developed which provides a relatively smooth transition from the semi-flexible blocked-out beam barrier (8- by 8-in. posts at 6-ft 3-in. O.C.) through a semi-rigid system (10- by 10-in. posts at 3-ft 1-1/2-in. O.C.) to a rigid reinforced concrete bridge rail.

KEY WORDS: Dynamic tests, impact tests, vehicle dynamics, guardrails, beams, anchorages, bridge approaches.

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# I. INTRODUCTION

Accident statistics[1] indicate the most frequent cause of fatalities on California highways is collision with fixed objects adjacent to the traveled way where errant vehicles impact guardrail installations, bridge abutments, bridge piers, bridge rails, lighting standards, sign supports, and other hazardous obstacles. In 1966 single vehicle run-off-the-road accidents accounted for approximately one half of the 2,200 fatalities on California state highways. Nearly 800 of these deaths involved vehicle impacts into fixed objects.

It is imperative that guardrails be placed only where a fixed object cannot be removed or made breakaway and where the potential hazard or risk of striking the rail would be less severe than either hitting an object or running down an embankment. Furthermore, if a section of guardrail is warranted (being considered the lesser hazard), it should not only be effective in protecting the motoring public by preventing penetration, but it should be as short as possible to avoid presenting an unnecessarily long target which will increase the probability of a collision.

Until recently, short sections of free standing unanchored corrugated metal beam guardrail (less than 100 feet) have been installed rather indiscriminately as protection from striking almost every conceivable highway appurtenance, many of which may have been less hazardous than the guardrail itself. Furthermore, the operational effectiveness of short sections of unanchored guardrail has not been satisfactory, particularly in high speed impacts.

It was the purpose of the research project discussed herein to investigate the effectiveness of free standing short sections of guardrail and to develop an effective end anchorage if considered necessary.

This work was accomplished in cooperation with the United States Department of Transportation, Federal Highway Administration, Bureau of Public Roads, as Item D-4-37 of Work Program HPR-1 (4), Part I, Research. The opinions, findings, and conclusions expressed in this publication are those of the authors and not necessarily those of the Bureau of Public Roads.

## II. OBJECTIVE

This project was initiated to determine the effectiveness of short lengths of unanchored guardrail and to develop an effective end anchorage system for corrugated metal beam guardrail, both free-standing and as a bridge approach flare.

## III. CONCLUSIONS

The following conclusions relative to corrugated metal beam guardrail are based on analysis of the results of the full scale tests conducted during this test series, involving vehicles weighing over 4,000 pounds, as well as operational experience.

1. The results of Tests 131 and 132 indicate that unanchored corrugated metal beam guardrail up to 62.5 ft in length is ineffective under severe impact loading. These tests further indicate that any unanchored guardrail section, regardless of length, is vulnerable when struck within 30 ft of either end.

2. Although Test 133 demonstrated the structural adequacy of the "Texas Twist" design in providing effective anchorage for short sections of guardrail, Test 134 showed that a hazardous condition exists when vehicle impact occurs at the upstream sloping end anchorage.

3. Tests 135 and 137 illustrated the effectiveness of the cable type end anchorage in preventing penetration of vehicles impacting short lengths of guardrail.

4. Test 135 indicated that a parabolic layout line for an anchored guardrail section will increase the likelihood of pocketing over that of a straight section between the same two end anchor points under similar conditions of impact.

5. Test 138 indicated that the effect of a high speed oblique angle impact into the upstream end of a cable anchored guardrail, although severe, is less hazardous than a similar impact into sloping beam guardrail end anchorage systems. This would be particularly true for flared lengths of guardrail where the chances of end impact are minimized.

6. Test 136 pointed out the need for more rigidity in the bridge approach guardrail near the concrete parapet to provide a smooth transition from the semi-flexible corrugated beam guardrail to the rigid bridge rail. Results of this test also indicated the need for a structurally adequate and properly blocked-out connection of the guardrail beam to the bridge rail parapet.

7. Test 137 proved that the deficiencies observed in Test 136 could be corrected by halving the guardrail post spacing, increasing the post size adjacent to the bridge rail, and by using a structurally adequate blocked-out connection to the bridge rail parapet.

8. The results of this series indicate that washers placed under the heads of the through bolts in the metal beam to post connection are effective in minimizing bolt pull through failures. The California Division of Highways now uses 3- by 1 3/4-in. by 3/16-in. rectangular plate washers under the head of the through bolts.

## IV. DISCUSSION

### A. Test Parameters

The test vehicles used in this study were 1964-66 Dodge sedans weighing approximately 4500 lbs. with dummy and instrumentation. Utilizing their own power, they were guided into the guardrail test installations by radio remote control. Impact speeds ranged from 56 to 63 mph at approach angles of 24 to 33 degrees.

The procedures taken to prepare, remotely control and target the test vehicles were generally similar to those used in past test series and are detailed in previous California Division of Highways reports[2,3]. All tests generally followed the criteria outlined by the HRB Committee on Guardrails and Guideposts for full scale testing of guardrails[4].

### B. Instrumentation

Photographic and mechanical instrumentation procedures and equipment employed in this test series were generally similar to those used in past test series and are detailed in previous California Division of Highways reports[2,3].

### C. Design and Performance

Common to each of the test installations was the guardrail design. The current California Division of Highways standard metal beam guardrail consists of a 12 gage (0.105 in.) corrugated steel beam mounted 27-in. high over-all, blocked-out with 8- by 8-in. by 1-ft 2-in. treated Douglas fir blocks on 8- by 8-in. by 5-ft 4-in. treated Douglas fir posts spaced 6-ft 3-in. on centers. The then current standard plans specified a 5/8-in. carriage bolt and hex nut for attaching the metal beam and block-out block to the post with a round cut washer under the nut only, Exhibit 4 (Appendix). In lieu of this, a 5/8-in. machine bolt with a round cut washer under both the head and the nut or a rectangular plate washer under the head and the round cut washer under the nut were used in these tests. It was felt that the increased bearing surface on the face of the beam provided for by the round cut washer (approximately 2.10 vs. 1.05 sq. in.) might prevent the bolt pull through failures observed in a previous test series on guardrails[2].

Each of the eight guardrail test installations differed in length and/or end anchorage system as discussed below.

#### 1. Test 131

The installation for Test 131 consisted of a 37.5-ft free standing section of unanchored guardrail (Figure 1). This test installation was similar to many operational installations currently installed along California highways except for the aforementioned machine bolts and round cut washers.

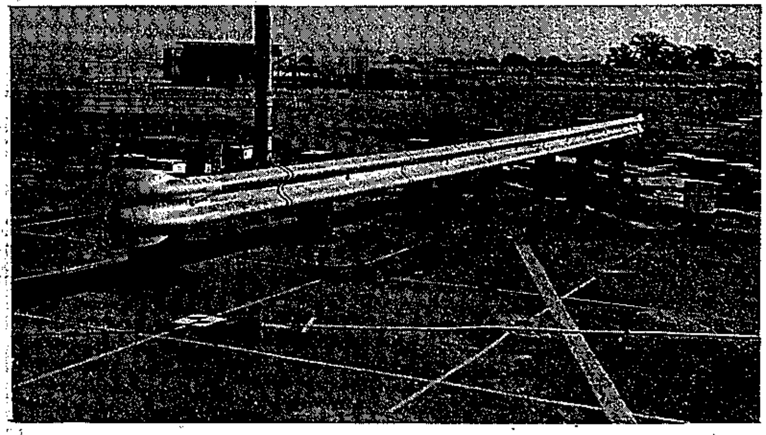


Figure 1

The test vehicle in Test 131 impacted the barrier near the center post at 63 mph/25 deg. The beam pocketed almost immediately upon impact (Figure 2), was pulled free of all but one of the posts, and was dragged, intact, by the vehicle as it penetrated through the installation with only a 3-deg change in direction, Plate A (Appendix).

Figure 2

The tendency of this short barrier to deflect laterally as a unit indicated that the combined resistance of the beam-to-post connections is less than the strength of the beam and was not sufficiently rigid to contain the impacting vehicle. The bolt-washer modification appeared to add sufficient bearing area at the face of the beam to resist bolt pull through. This was evident in that only one bolt pull through failure was observed, while the other six bolts pulled free at the posts and remained attached to the beam. This would indicate that the increased area provided by the washers help in transmitting impact tensile beam loads.

All beam sections, posts, and block-out blocks were damaged (Figure 3). The vehicle sustained major front end damage and was considered a total loss (Figure 4).

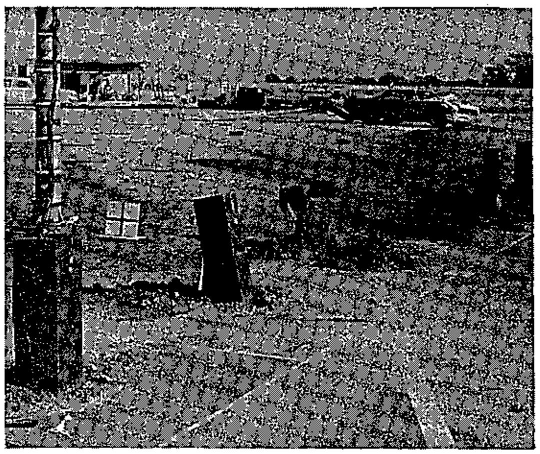


Figure 3

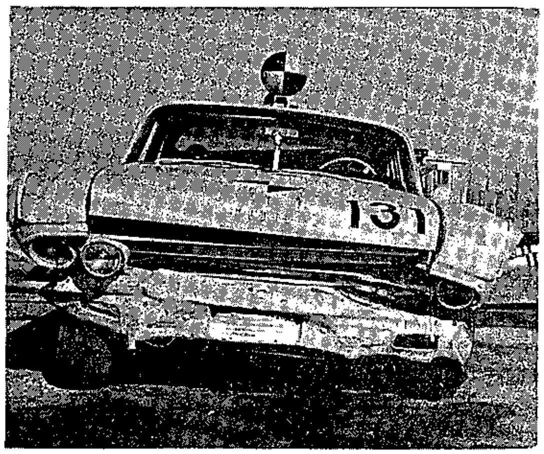



Figure 4

2. Test 132

Because Test 131 clearly demonstrated that an unanchored 37.5-ft guardrail section was totally inadequate, the unanchored barrier length for Test 132 was increased to 62.5 ft. In an attempt to increase end rigidity, a slight flare was formed by modifying the block-out blocks at each end of the installation. The two end posts used no blocks and the second post from each end used 4-in. thick blocks (Figures 5a and 5b). At all four of these posts the bolt-round cut washer modification was installed. However, washers were not used under the heads of the through bolts in order to obtain a comparison with

Test 131 where washers apparently prevented bolt "pull through" failures.

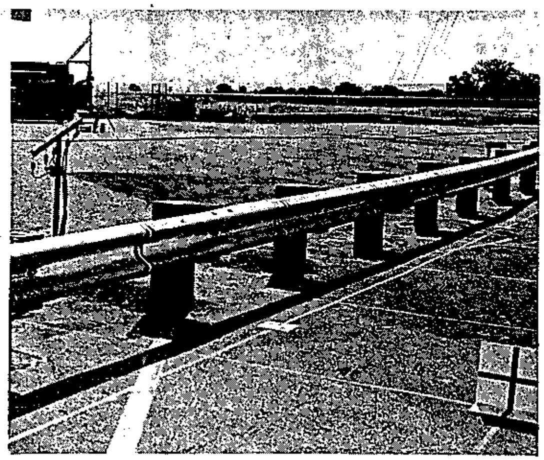


Figure 5a

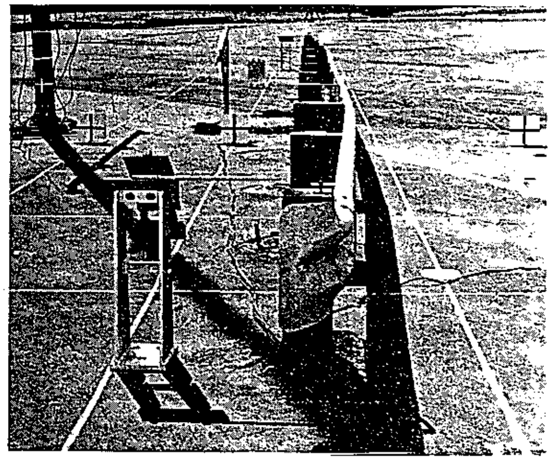


Figure 5b

The test vehicle in Test 132 impacted the barrier 2-ft downstream of post 4 at 61 mph/25 deg. As in Test 131, the beam was pulled free from the posts and dragged, intact, by the vehicle as it penetrated through the barrier with a 6-deg redirection angle, Plate B (Appendix). The additional barrier length was still not sufficient to prevent a repeat of the failure experienced in Test 131. The number of posts in a 62.5-ft section of guardrail was insufficient to develop the combined beam-to-post strength required to resist the axial load imposed by a severe impact.

Although the over-all results of this test would probably not have been significantly different had round cut or rectangular plate washers been used under all bolt heads, it is notable that six out of the seven bolts without washers pulled through the metal beam. The transfer of the high axial load to the posts prior to the "pull through" failures was evident in that ten of the eleven posts were split.

All beam sections, posts, and block-out blocks were damaged (Figure 6).

The vehicle sustained major front end damage and was considered a total loss (Figure 7).

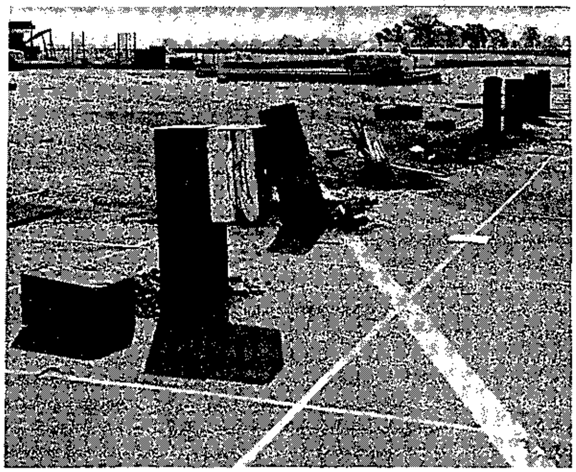


Figure 6

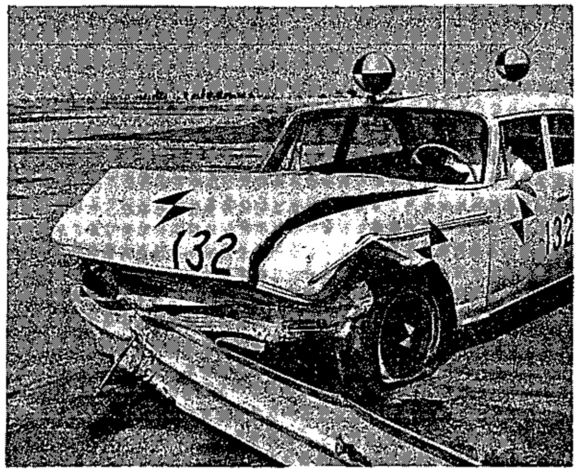



Figure 7

3. <u>Test 133</u>

The results of Tests 131 and 132 clearly demonstrated that the impact load introduced into the beam on short lengths of guardrail must be transmitted to the soil by some means other than through the posts via the post-to-beam connectors. A beam end anchorage system appeared to be the best solution.

The first guardrail end anchorage design tested was developed by the Texas Highway Department and is referred to as the "Texas Twist". The test installation for Tests 133 and 134 consisted of a 62.5-ft section of guardrail with 18-ft 9-in. of the beam section at each end twisted 90 deg axially, bent down and bolted to fabricated steel posts cast in 18-in. diameter by 5-ft deep cylindrical concrete footings, Exhibit 3 (Appendix). There was no intermediate support in the sloping end sections between the concrete footing and the first post. The center 25-ft of the installation conformed to the California standard 27-in. high metal beam guardrail with round cut washers installed under the heads of all through bolts (Figure 8).

The vehicle in Test 133 impacted the barrier approximately 2-ft downstream of post 2 at 56 mph/30 deg and remained in contact for the remaining 35-ft of barrier before being effectively redirected at an exit angle of 7 deg, Plate C (Appendix). There was only a moderate

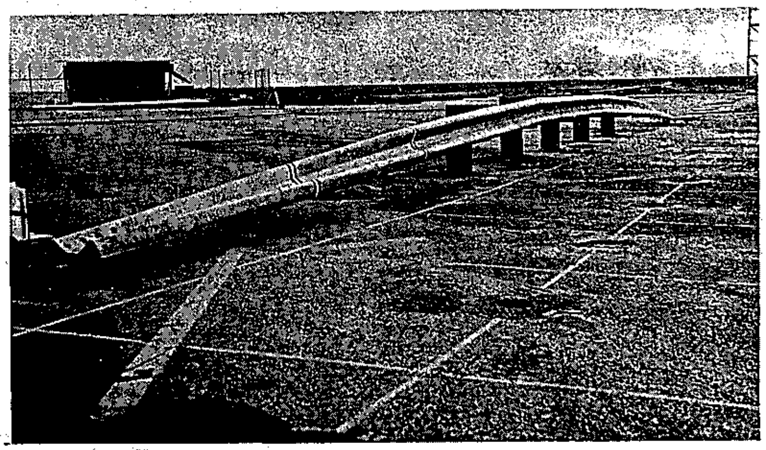


Figure 8

amount of vehicle roll even though the barrier posts all rotated back through a considerable angle (maximum permanent rotation 43 deg, maximum dynamic rotation 46 deg) illustrating the effectiveness of the blocked-out beam principle. There were permanent beam deflections of 2.8 ft horizontal (back) and 6 in. vertical (up).

All beam sections were damaged as were two block-out blocks and one post. There were no bolt pull through failures. A 1/3-in. wide crack was opened in the downstream concrete footing which was displaced approximately 1/2 in. toward impact. The upstream concrete footing was displaced 2 1/2 in. toward impact (Figure 9) indicating the high tensile force transmitted by the guardrail beam.

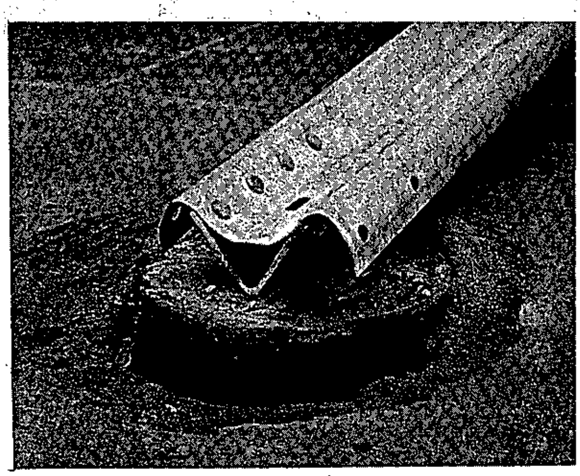


Figure 9

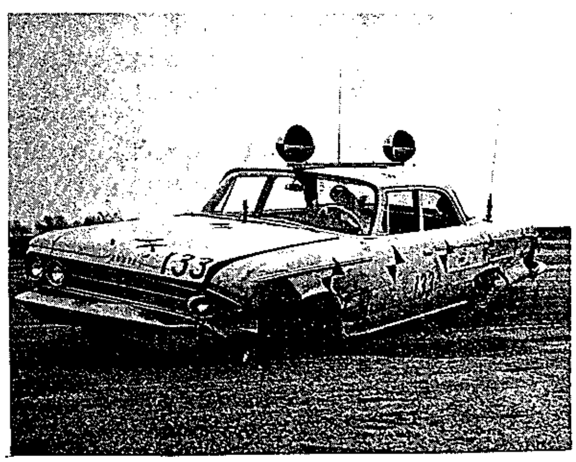


Figure 10

The effectiveness of the sloped beam end anchors was further demonstrated by the fact that none of the five timber posts were split. Although the posts rotated back excessively, the anchors provided sufficient support for the beaming or "bowstring" action to take place; thus permitting the development of sufficient axial force for effective vehicle redirection.

The vehicle sustained moderate damage as shown in Figure 10.

4. Test 134

Although Test 133 demonstrated the structural adequacy of the "Texas Twist" anchorage system, it was felt that the geometric characteristic of the sloping beam end anchorage presents a potentially hazardous condition in that it provides a ramp which an impacting vehicle might climb and vault the barrier. Therefore, for this next test the point of impact was changed to within the upstream sloping beam section, 4.9 ft from the concrete footing. The barrier installation was identical to that tested in Test 133.

The test vehicle in Test 134 impacted the barrier at the planned point of impact at 63 mph/24 deg. The beam at this point was too low to effectively resist the vertical downward force of the impacting left front wheel which deflected the beam down, permitting the vehicle to ride up and over the beam. This imparted a counter-clockwise rolling moment to the vehicle which completely overturned as it vaulted the barrier coming to rest 180 ft beyond impact in a regained upright position, Plate D (Appendix).

The end section of beam was destroyed and one post and block-out block shattered (Figure 11). The vehicle sustained major front, side, and top damage, and was considered a total loss (Figure 12).

Figure 11

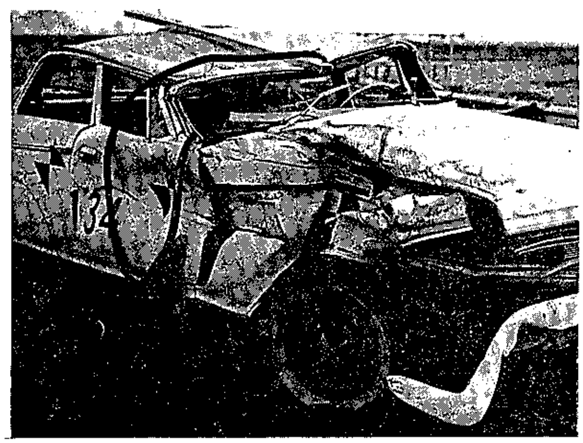


Figure 12

These test results were later substantiated by a test on a sloped beam end anchorage design by the Ontario Highway Department[5] in which similar vehicle reaction was observed.

5. Test 135

The next attempt to provide adequate end anchorage was the development of a cable end anchor system which has subsequently been adopted as a California Standard, Exhibit 1 (Appendix). Test 135 was the first test using this system of anchorage.

The test installation consisted of a 50-ft length of corrugated metal beam guardrail constructed on a parabolic flare. In order to reduce the lever arm effect of the axial force acting about the posts, block-out blocks were not installed on the end posts and 4-in. thick blocks were used on the posts next to the end. Round cut washers were used under all bolt heads. Each end section of the beam was secured with a 3/4-in. steel cable (breaking strength 21.4-tons) attached to the beam with a special fitting between the first and second posts (Figure 13).

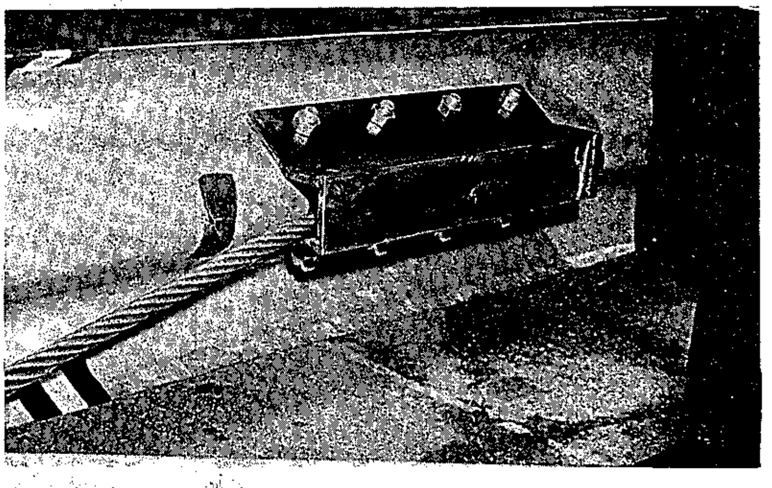


Figure 13

The other end of each cable was clamped to a 1 1/4-in. eye bolt attached to a steel 8 WF 17 section cast in an 18-in. dia by 5-ft deep cylindrical concrete footing (Figures 14 and 15).

The test vehicle in Test 135 impacted the barrier between posts 2 and 3 at 59 mph/28 deg and remained in contact with the barrier for approximately 22 ft before being effectively redirected at an exit angle of 24 deg, Plate E (Appendix).

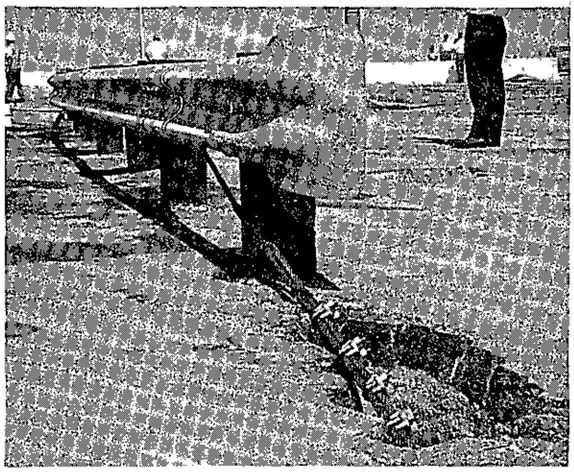


Figure 14

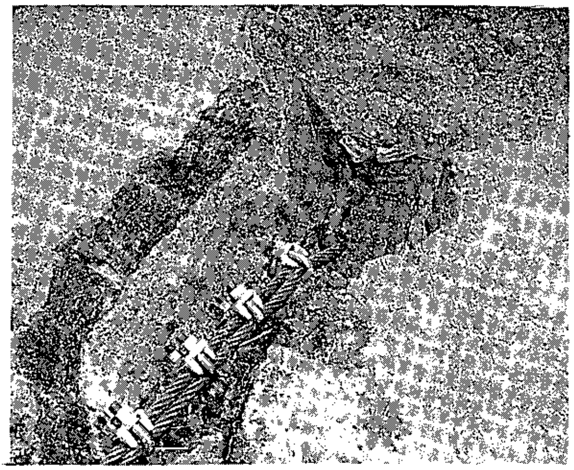


Figure 15

The magnitude of the impact force transmitted from the beam into the cable end anchors was indicated by displacement of the upstream concrete footing 3/4 in. and of the downstream footing 1/2 in., both toward impact. The beam was warped slightly where the cable connection fitting was attached, indicating that it was under substantial load through impact.

All beam sections were damaged. There were no bolt pull through failures although two block-out blocks crushed and one post was broken (Figure 16). The vehicle sustained moderate front end damage (Figure 17).

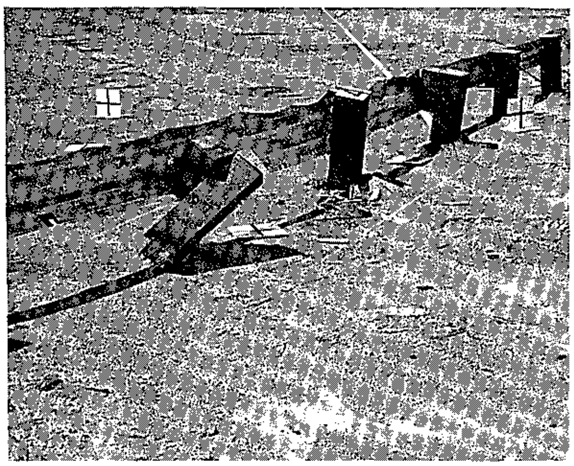


Figure 16

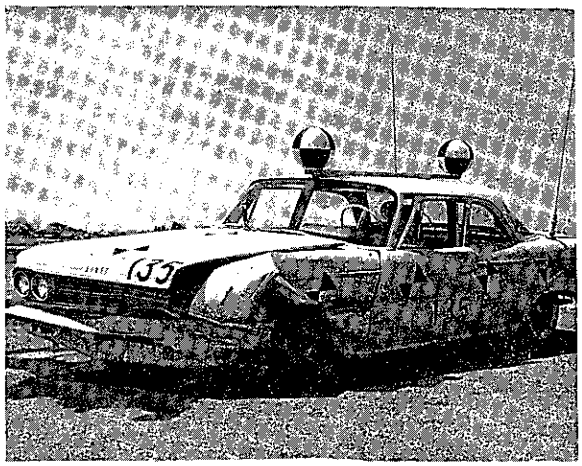


Figure 17

Although vehicle dynamics and barrier reaction were considered satisfactory through impact, deceleration forces were fairly severe as there was a tendency for the vehicle to pocket the beam. Analysis of high speed data film revealed that this pocketing was due, at least partially, to the parabolic configuration of the barrier, since the curved beam had to deform through a straight line before the restraining force of the anchors was effectively developed. As a result, it is recommended that flares be placed on a straight line between anchor points, particularly on short sections, even though there is a possibility of increasing the collision impact angle by doing so.

6. Test 136

The success of the cable anchor in providing adequate beaming strength to a short section of guardrail prompted Test 136 where it was used to anchor the upstream end of a bridge guardrail approach flare. The test installation for Test 136 consisted of a 53-ft section of metal beam guardrail with the initial 12 ft at the downstream end constructed with enough curvature that the remaining 41 ft could be installed on a straight line thus forming a 4-ft offset from the face of a simulated bridge end post (Figure 18). The metal beam at the downstream end was secured to the nonreinforced concrete simulated bridge end post with two 1-in. dia high strength bolts. The bolts were inserted through 1-1/8 in. dia holes bored through the concrete. An 8- by 12- by 18-in. wood block-out block was placed between the guardrail beam and the concrete (Figure 19).

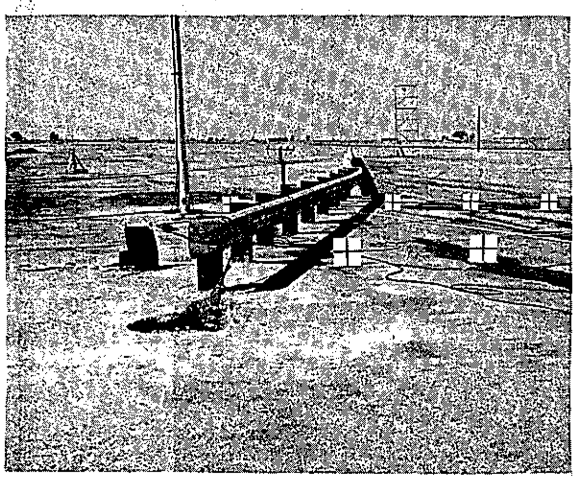


Figure 18

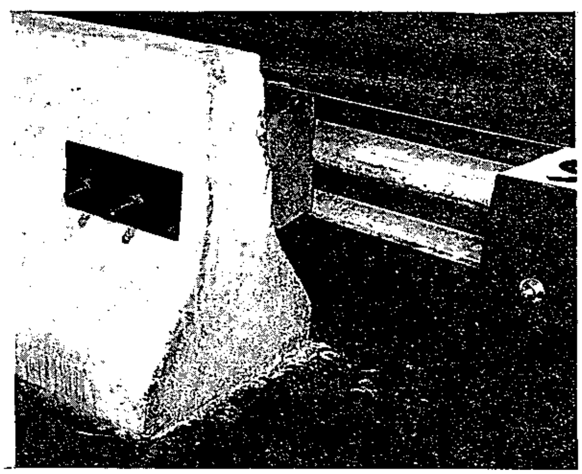


Figure 19

The upstream end of the metal beam guardrail was anchored with the cable anchor design tested in Test 135. Data from the preceding tests indicated that the use of round cut washers under the heads of the through bolts did assist in preventing bolt pull through failures. It was also evident that when the guardrail beam is adequately anchored, as in Test 135 the probability of bolt pull through failures or post splitting is minimized under those impact conditions. However, under a more severe impact it is conceivable that even with round cut washers, bolt pull through failures could occur. Consequently, it was decided that for Test 136 the round cut washers would be replaced with a 3- by 1-3/4- by 3/16-in. steel plate washers to provide additional bearing surface under the through bolt heads (Figure 20).

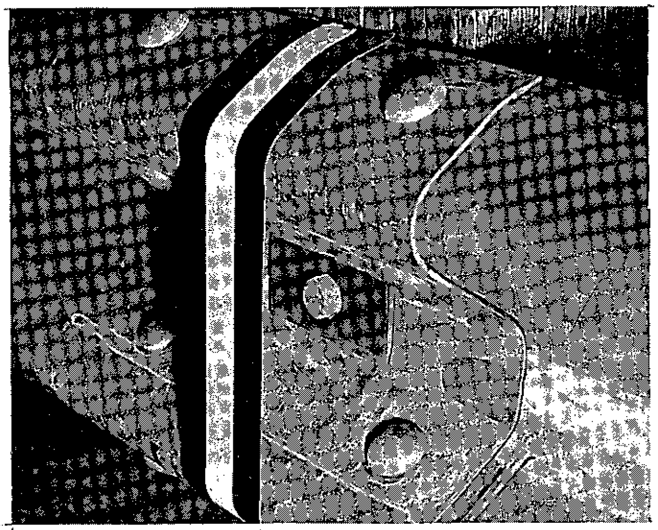


Figure 20

The test vehicle in Test 136 impacted the barrier 18-ft upstream of the simulated bridge end post at 60 mph/33 deg. pocketing the beam severely (Figure 21).

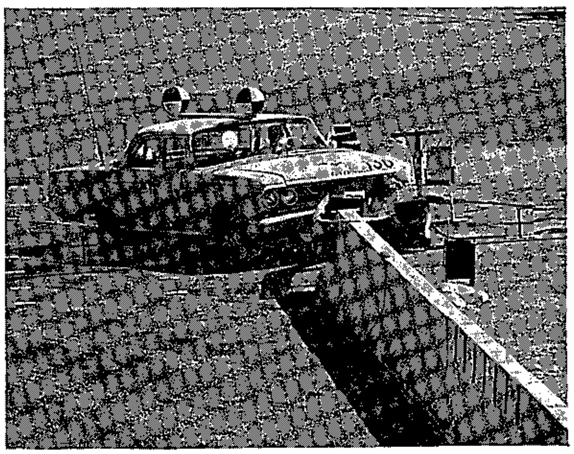


Figure 21

As the vehicle was being redirected (approximately 12 deg) the concrete end post failed through the connecting holes, allowing the guardrail beam to pull free, thus permitting the vehicle to penetrate the barrier. As the vehicle progressed through impact, the right front wheel struck the end of the concrete end post throwing the vehicle into a violent counter clockwise roll-over. The vehicle came to rest 45 ft beyond impact in a regained upright position (Figure 22), Plate F (Appendix).

Two sections of beam were damaged. Although barrier damage was considered severe with three timber posts broken off and four block-out blocks shattered, there were no bolt pull through failures. The vehicle sustained major front, side, and top damage and was considered a total loss (Figure 23).

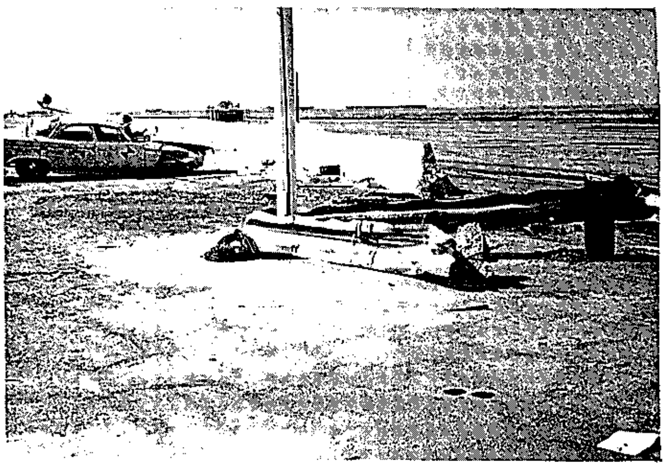


Figure 22


Figure 23

Analysis of the data film indicates that even if the concrete end post had not failed, beam deflection and pocketing were already occurring to such an extent that the vehicle would not have been redirected sufficiently to avoid an end-on collision into the concrete bridge end post.

7. <u>Test 137</u>

To correct the deficiencies noted in Test 136, several modifications were made for the Test 137 installation. To more accurately depict an operational installation, a California Standard Type 1 bridge rail parapet end post was constructed of reinforced concrete in accordance with design details of the then current California Division of Highways Standard Plans, Exhibit 2 (Appendix). A 50-ft section of metal beam guardrail was constructed on a straight line with the upstream end offset 4 ft from the projected face of the bridge end post (Figure 24). The same cable anchorage installation used in Test 136 was employed to anchor the upstream end, Exhibit 1 (Appendix).

The block-out block between the guardrail beam and the concrete was fabricated of 1/4-in. steel plate rather than the wood block used in the preceding test (Figure 25). This was done to add rigidity to the system and prevent the crushing of the block.

Finally, to minimize the pocketing noted in Test 136 and to provide improved transition from the semi-flexible metal beam guardrail to the rigid concrete bridge rail, the guardrail post spacing near the concrete bridge end post was decreased to 3-ft 1-1/2-in. Also the three timber guardrail posts nearest to the bridge rail end were 10- by 10-in. rather than the standard 8- by 8-in. posts. Steel plate washers were used on all through bolts as in the preceding Test 136.

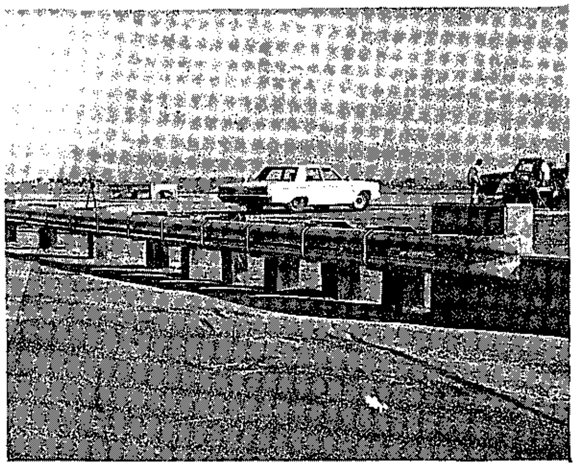


Figure 24

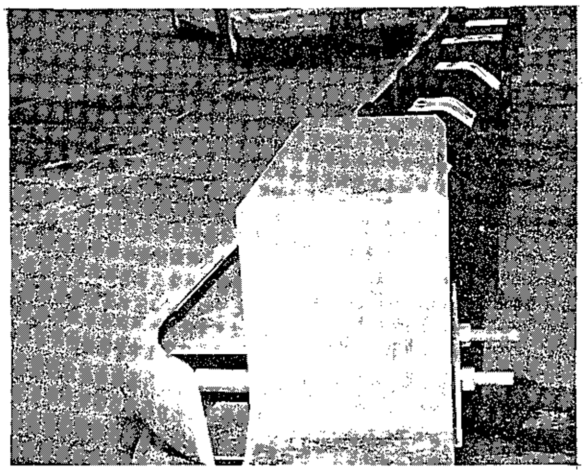


Figure 25

The vehicle in Test 137 impacted near the center of the guardrail at 61 mph/27 deg and remained in contact with the barrier for approximately 22 ft before being effectively redirected at an exit angle of 16 deg, Plate G (Appendix).

Three sections of beam were damaged, two timber posts broken off and two block-out blocks shattered. Again, there were no bolt pull through failures. The guardrail beam sustained a permanent lateral deflection of 2.1 ft (Figure 26).

Even though vehicle dynamics in this high speed oblique angle collision were considered good through impact, the left front wheel was torn off the test vehicle which sustained major front end and undercarriage damage as shown in Figure 27.

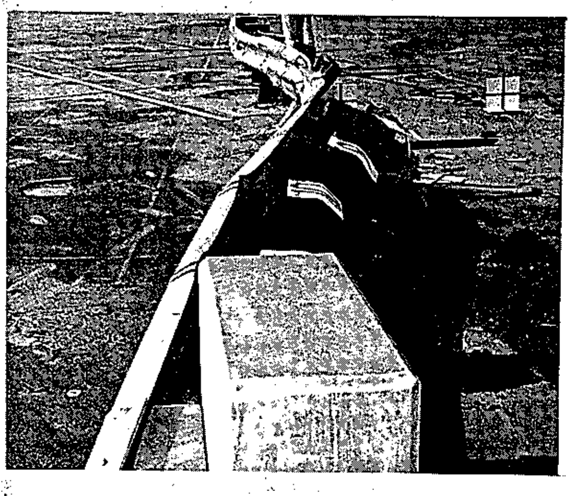


Figure 26


Figure 27

8. <u>Test 138</u>

The chances for beam "spearing" from a direct end-on collision into the offset end of a guardrail flare are not great. However, the upstream end anchor does present a potential hazard. Therefore, it was considered essential to obtain some indication of what would occur during a collision at or near the upstream cable anchorage system.

The barrier installation for Test 138 was identical to that utilized in Test 137.

The test vehicle in Test 138 impacted the metal beam end terminal section at 61 mph/25 deg, upstream of where the end anchor cable attached to the beam. The left front wheel rode up and over the cable anchor eye-bolt and the vehicle, straddling the cable, impacted post 1. The cable parted in tension as the vehicle, pushing the beam ahead of it, penetrated the barrier, Plate H (Appendix).

The first two posts were broken off at ground level and completely shattered. The end 12-ft of metal beam guardrail was twisted and doubled back around post 3 which was deflected laterally 0.7 ft. The remainder of the barrier was intact with no significant movement or damage (Figure 28). There were no bolt through failures. This again illustrates the effectiveness of the plate washers, which have subsequently been adopted as a California standard for use on guardrailing.

The vehicle sustained major front end damage with both front wheels smashed back under the engine compartment and was considered a total loss (Figure 29).

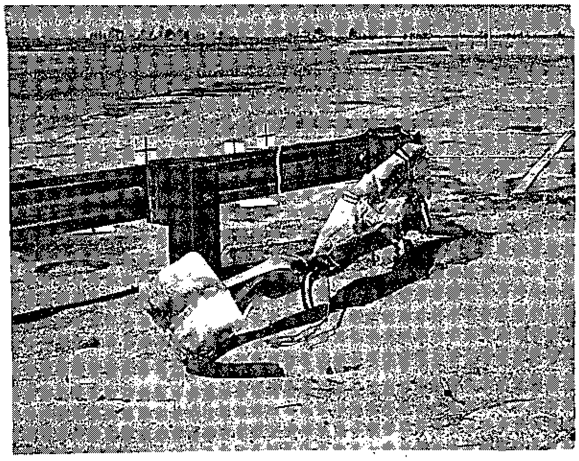


Figure 28


Figure 29

It is significant to note that although the cable parted and the vehicle penetrated the barrier, there was no roll-over action and deceleration forces were no more severe than those recorded in Test 137. However, the primary decelerating force was in the longitudinal direction (the more critical) rather than in the lateral direction as experienced in most oblique angle barrier impacts.

D. Operational Considerations

All current guardrail end anchorage systems present potential hazards to impacting vehicles. However, based on Tests 134 and 138 of this test series in conjunction with California's operational experience, the cable anchorage system is considered less hazardous than the sloping beam type, particularly at locations where space is available to flare, or offset, the upstream end of the guardrail away from the traveled way. This is based on the following factors:

1. Although the chance of beam "spearing" an impacting vehicle is eliminated with the "sloped-beam" end

anchorage system, California accident statistics indicate that this has been an infrequent occurrence on flared or offset end guardrail installations.

2. The more hazardous and less effective length which must extend beyond the point of theoretical need at the upstream end of a guardrail installation is approximately 4 ft for the cable anchorage compared to at least 12 ft for the sloped beam system.

3. The cable end anchorage system is designed to prevent barrier penetration, even under severe impact conditions, if impact occurs downstream of the cable-beam attachment point. Furthermore, a vehicle impacting upstream of this point as in Test 138 may penetrate the barrier without experiencing beam "spearing", the severe deceleration forces that generally accompany snagging as in Test 136, or the violent vehicle kinematics observed in Test 134.

Therefore, since the potential severity of impact into the cable anchorage system appears to be no greater than into the sloped beam system, and the probability of impact appears to be significantly less due to its shorter length, the cable end anchorage system appears to be the best alternative.

It should also be remembered that since a guardrail itself is a fixed object, its length should be held to an absolute minimum.

## V. REFERENCES


1. "Accidents, Safety, and the Division of Highways", California Division of Highways, Traffic Department Statistics, December 28, 1967.

2. Field, R. N. and Prysock, R. H., "Dynamic Full Scale Impact Tests of Double Blocked-Out Metal Beam Barriers and Metal Beam Guardrailing, Series X", California Division of Highways, February 1965.

3. Nordlin, E. F., Field, R. N., and Hackett, R. P., "Dynamic Full Scale Impact Tests of Bridge Barrier Rails", California Department of Public Works, presented at the 43rd Annual HRB Meeting, January 1964.

4. Highway Research Board Committee on Guardrails and Guide Posts, "Proposed Full-Scale Testing Procedures for Guardrails", Circular 482, September 1962.

5. Armstrong, M. D., Smith, P., Wolkowicz, M., and Jasper, R. G., "Full-Scale Impact Tests on Low Cost Barrier Systems, Lighting Poles and Sign Supports, 1967", Department of Highways, Ontario, D. H. O., Report No. 1R22.

6. Nordlin, Eric F. and Field, Robert N., "Dynamic Tests of Steel Box Beam and Concrete Median Barriers", presented at the 47th Annual HRB Meeting, January 1968.

7. Beaton, John L., Nordlin, Eric F., and Field, Robert N., "Dynamic Tests of Corrugated Metal Beam Guardrail", California Department of Public Works, Division of Highways, presented at the 46th Annual HRB Meeting, January 1967.

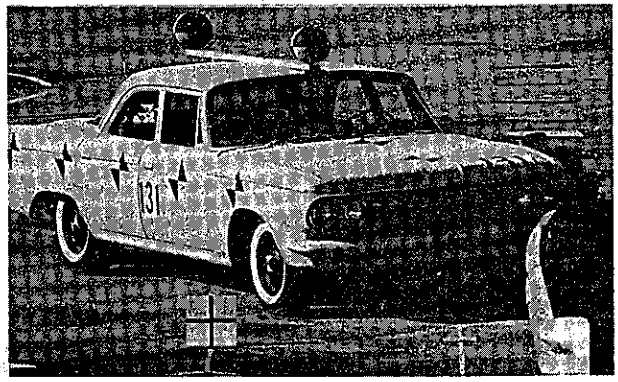
8. Michie, J. D. and Calcote, L. R., "Location, Selection, and Maintenance of Highway Guardrails and Median Barriers", National Cooperative Highway Research Program, Report 54.

# VI. APPENDIX

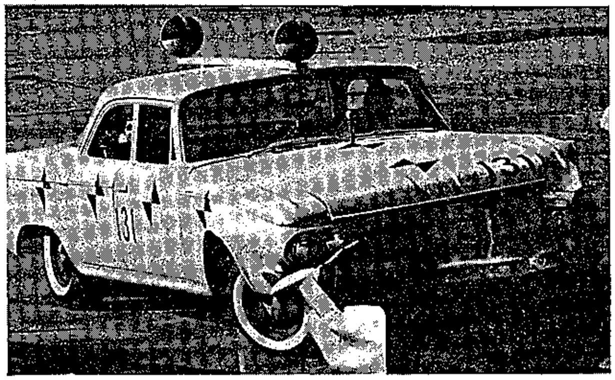
The following plates contain pertinent data and photographs of the impact tests discussed in the reports:

| | |
|---|---|
| Test 131 | Plate A |
| Test 132 | Plate B |
| Test 133 | Plate C |
| Test 134 | Plate D |
| Test 135 | Plate E |
| Test 136 | Plate F |
| Test 137 | Plate G |
| Test 138 | Plate H |
| Exhibit 1 | Cable End Anchorage Details |
| Exhibit 2 | Guardrail Connection Details at Concrete Bridge Abutment |
| Exhibit 3 | Texas Twist End Anchorage Details |
| Exhibit 4 | 1965 Standard Plan, Metal Beam Guardrailing and Metal Beam Barrier |

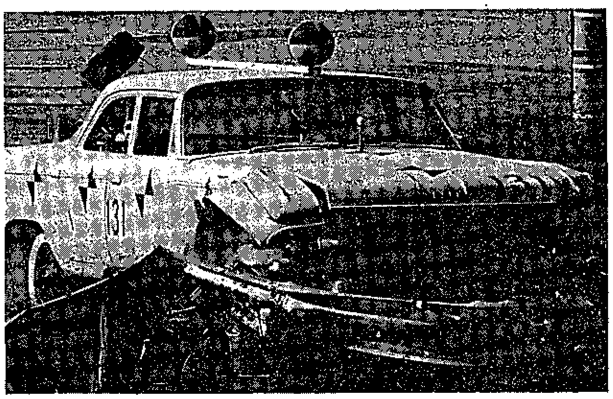
TEST 131 PLATE A



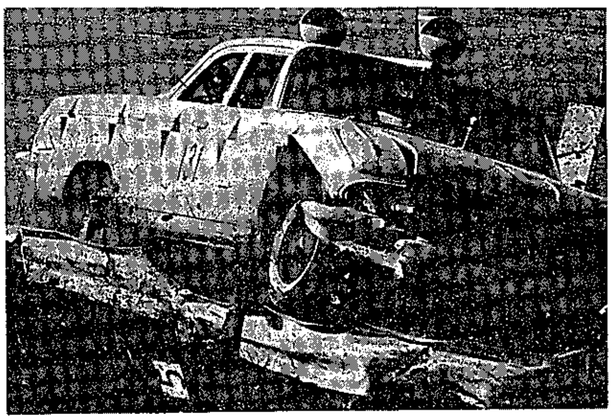
Impact + 0.03 Sec



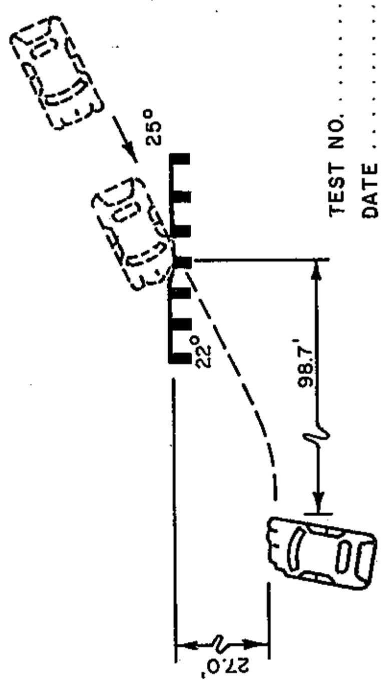
I + 0.15 Sec



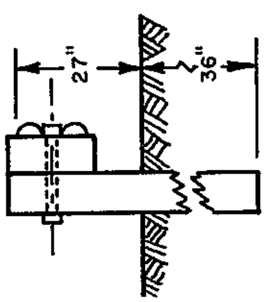
I + 0.35 Sec



I + 0.55 Sec




| | |
|---|---|
| TEST NO. | 131 |
| DATE | 11-30-65 |
| VEHICLE | 1964 Dodge Sedan |
| VEHICLE WEIGHT (W/DUMMY & INSTRUMENTATION) | 4540 # |
| IMPACT SPEED | 63 mph |
| IMPACT ANGLE | 25° |
| EXIT ANGLE | 22° |
| DUMMY RESTRAINT | Lap Belt |
| BEAM RAIL | 12 ga. Galv. Steel x 13'-6.5" |
| RUBBING RAIL | None |
| POST | 8" x 8" Rough D. F. x 5'-4" |
| POST EMBEDMENT | 36" |
| POST SPACING | 6'-3" |
| LENGTH OF INSTALLATION | 37.5' |
| GROUND CONDITION | Damp |



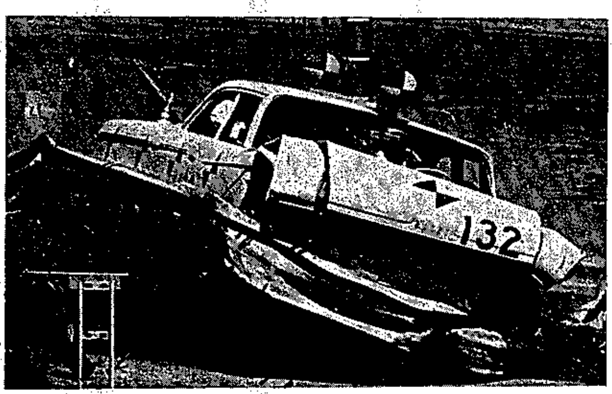

METAL BEAM GUARDRAIL

TEST 132 PLATE B

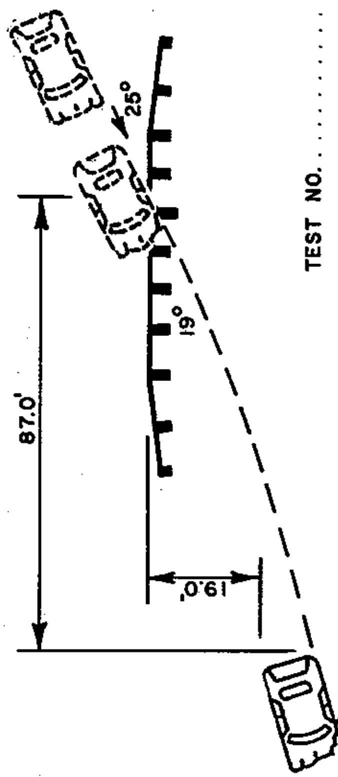
Impact + 0.04 Sec

I + 0.10 Sec

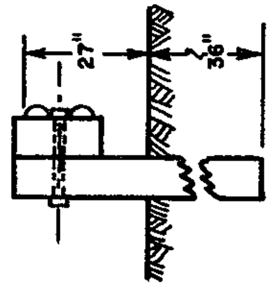
I + 0.30 Sec



I + 0.60 Sec

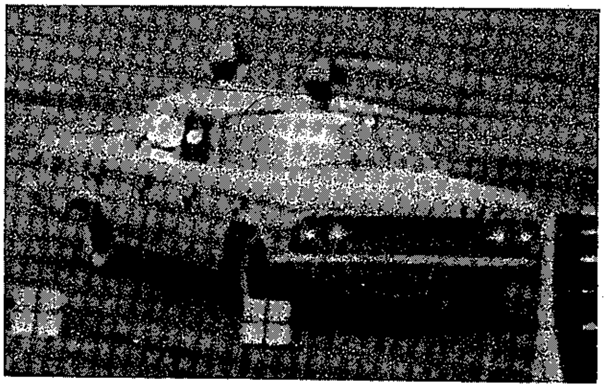



| | |
|---|---|
| TEST NO. | 132 |
| DATE | 6-15-66 |
| VEHICLE | 1964 Dodge Sedan |
| VEHICLE WEIGHT (W/DUMMY & INSTRUMENTATION) | 4540 # |
| IMPACT SPEED | 61 mph |
| IMPACT ANGLE | 25° |
| EXIT ANGLE | 19° |
| DUMMY RESTRAINT | Lap Belt |
| BEAM RAIL | 12 ga. Galv. Steel x 13'-6.5" |
| RUBBING RAIL | None |
| POST | 8"x8" Rough D.F. x 5'-4" |
| POST EMBEDMENT | 36" |
| POST SPACING | 6'-3" |
| LENGTH OF INSTALLATION | 62.5' |
| GROUND CONDITION | DRY |

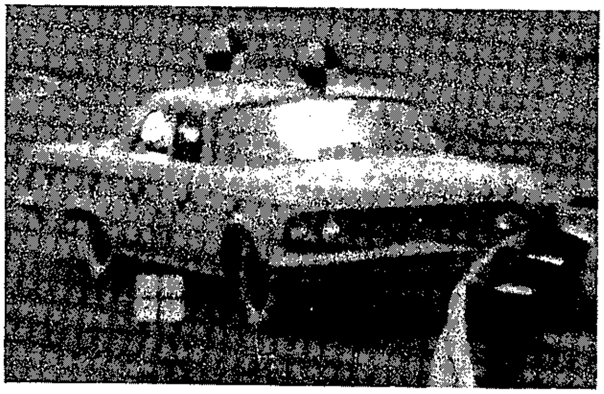



METAL BEAM GUARDRAIL

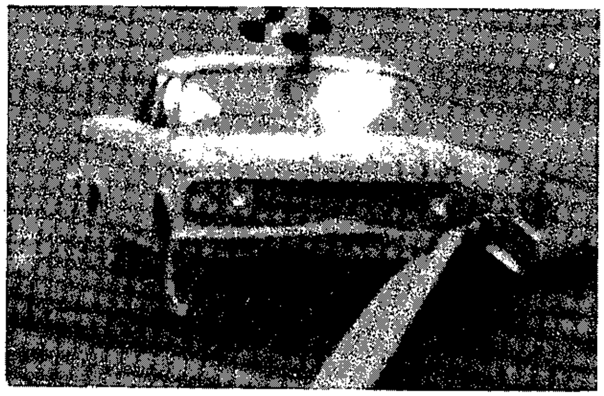
TEST 133 PLATE C



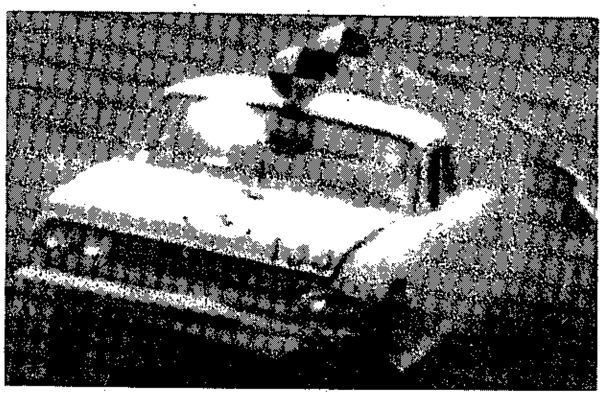
Impact



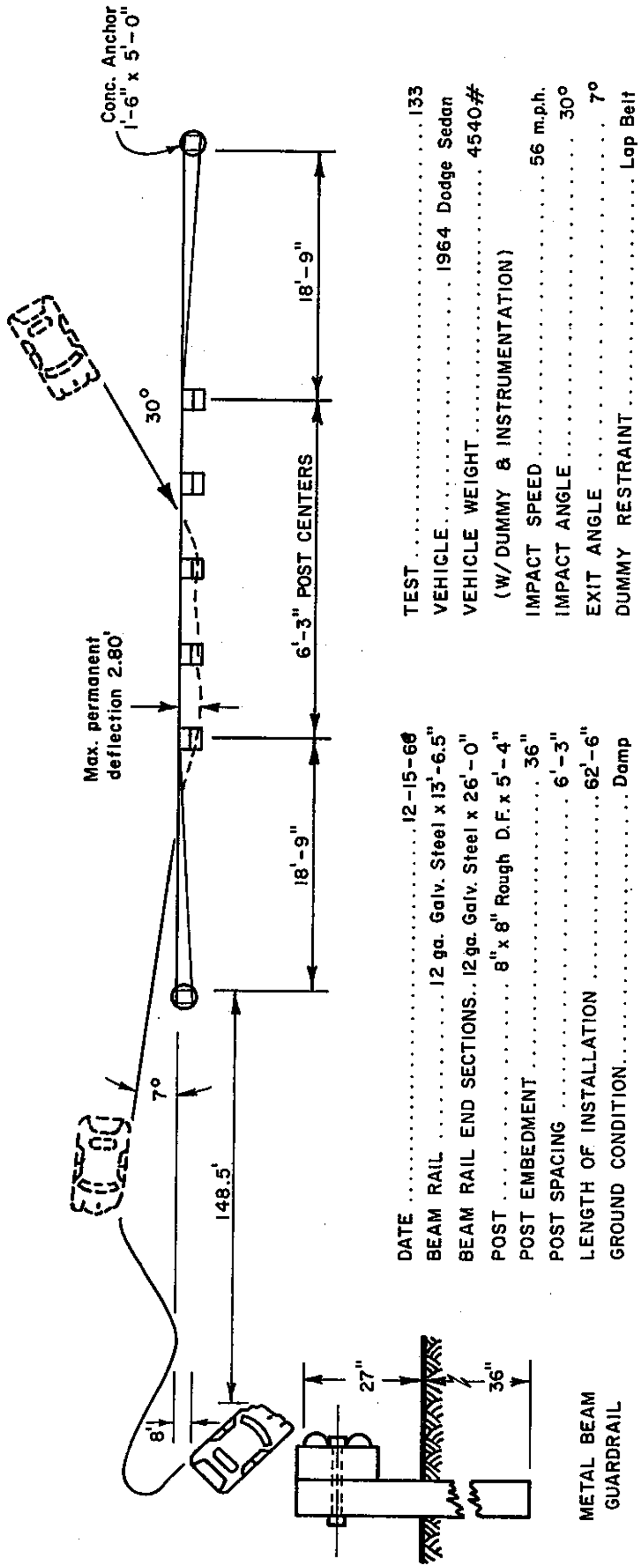
I + 0.10 Sec



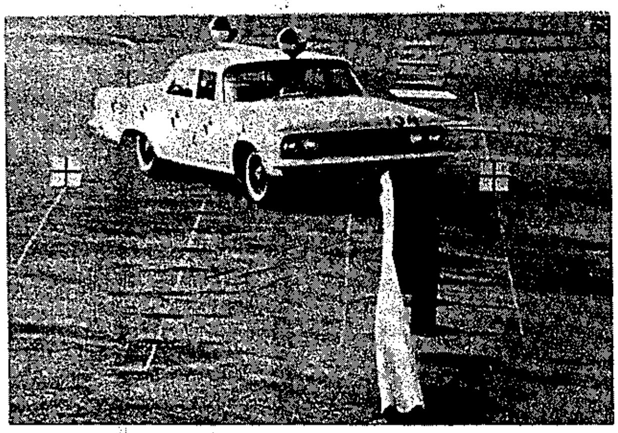
I + 0.25 Sec



I + 0.65 Sec

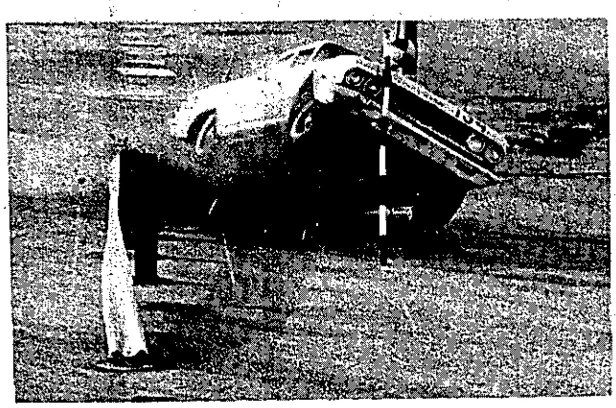


TEST 134 PLATE D



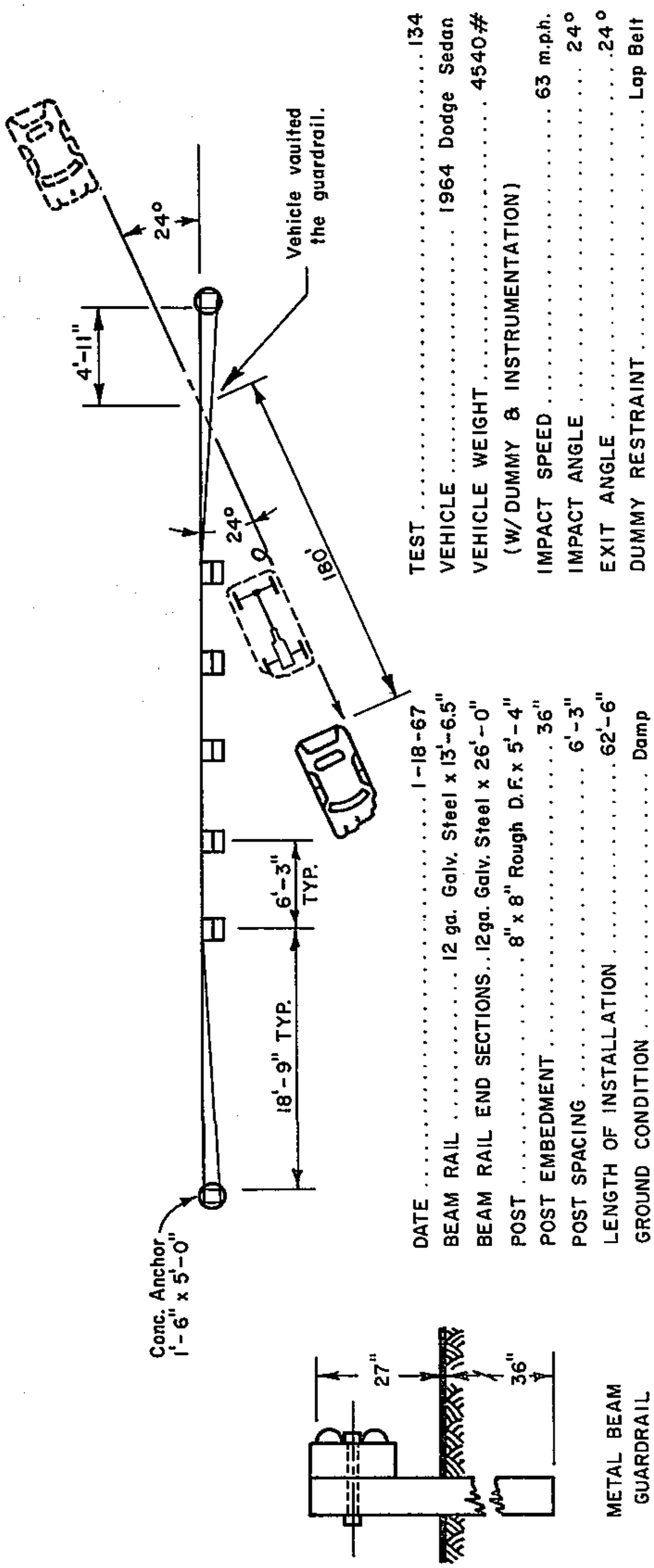
Impact

I + 0.25 Sec



I + 0.40 Sec

I + 0.50 Sec

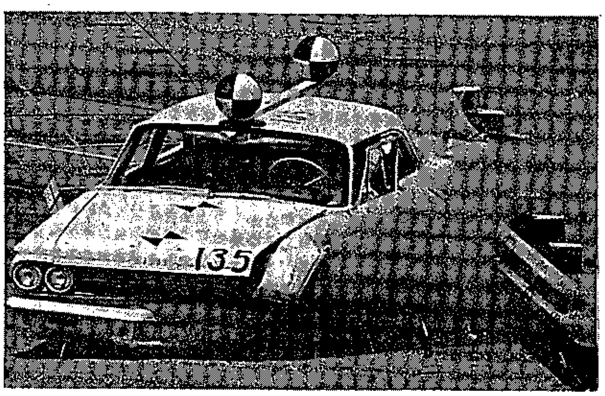


TEST 135 PLATE E

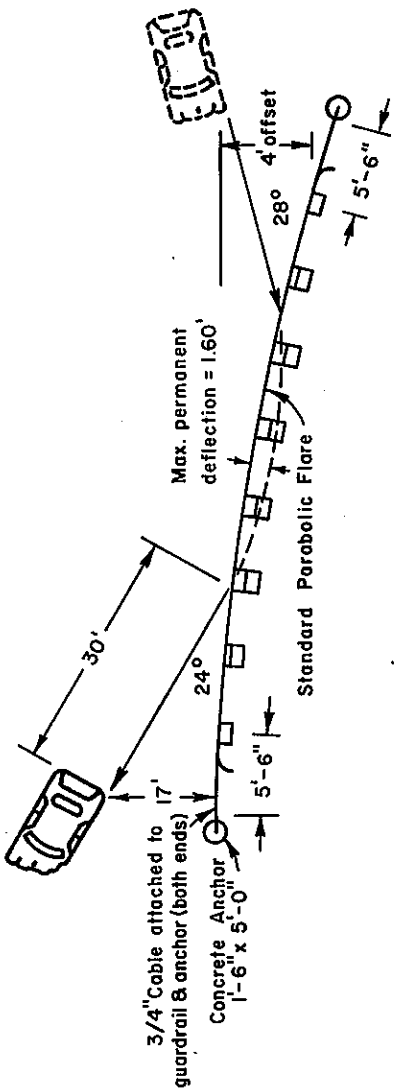
Impact

I + 0.25 Sec

I + 0.40 Sec

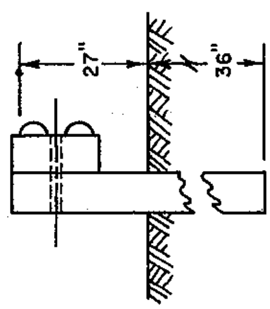


I + 0.80 Sec




TEST NO. . . . . . . . . . . . . . . . . . . .135
VEHICLE . . . . . . . . . . . . . . . .1964 Dodge Sedan
VEHICLE WEIGHT . . . . . . . . . . . . . . .4540 #
(W/DUMMY & INSTRUMENTATION)
IMPACT SPEED . . . . . . . . . . . . . . .59 m.p.h.
IMPACT ANGLE . . . . . . . . . . . . . . . .28°
EXIT ANGLE . . . . . . . . . . . . . . . . .24°
DUMMY RESTRAINT . . . . . . . . . . . . . .Lap Belt

DATE . . . . . . . . . . . . . . . . . .8-10-67
BEAM RAIL . . . . . . . . .12 ga. Galv. Steel x 13'-6.5"
POST . . . . . . . . . . . . .8" x 8" Rough D.F. x 5'-4"
POST EMBEDMENT . . . . . . . . . . . . . . . .36"
POST SPACING . . . . . . . . . . . . . . . .6'-3"
LENGTH OF INSTALLATION . . . . . . . . . . . . .50'
GROUND CONDITION . . . . . . . . . . . . . . .Dry




METAL BEAM GUARDRAIL

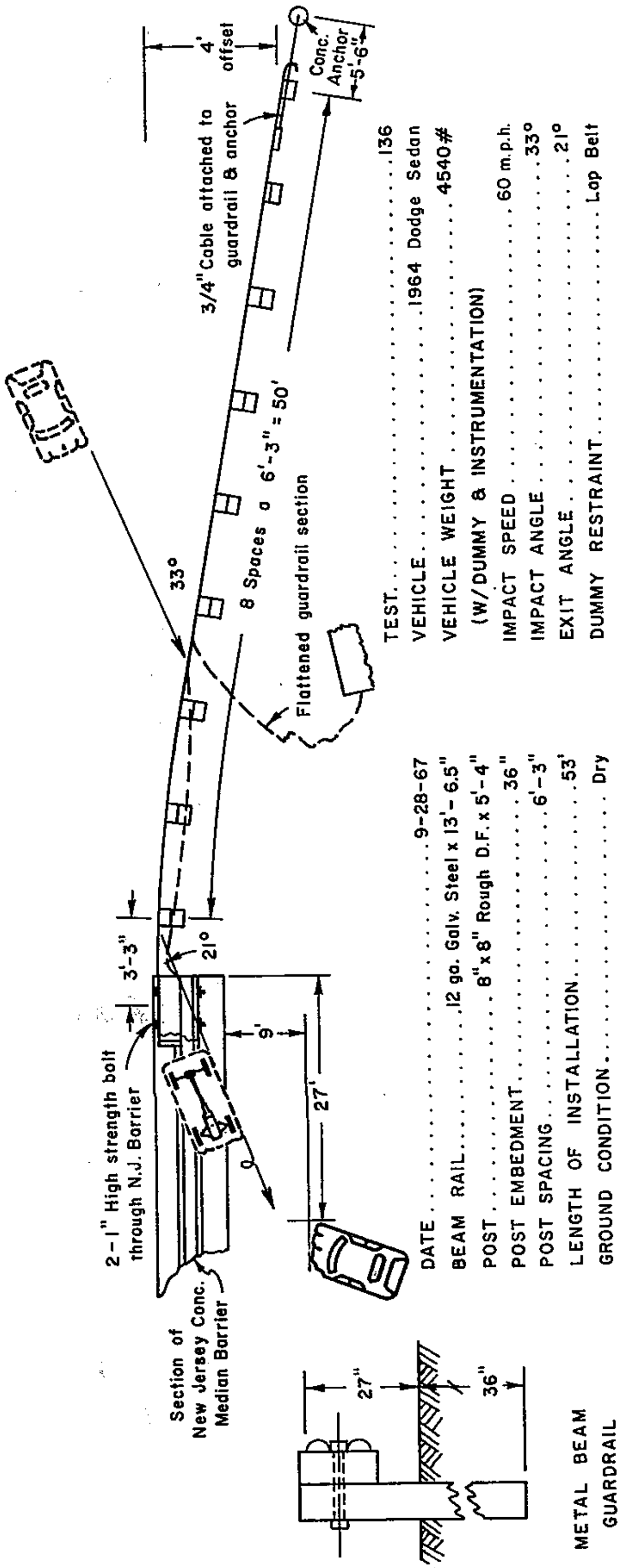
TEST 136 PLATE F

IMPACT

I + 0.10 Sec

I + 0.40 Sec

I + 0.55 Sec



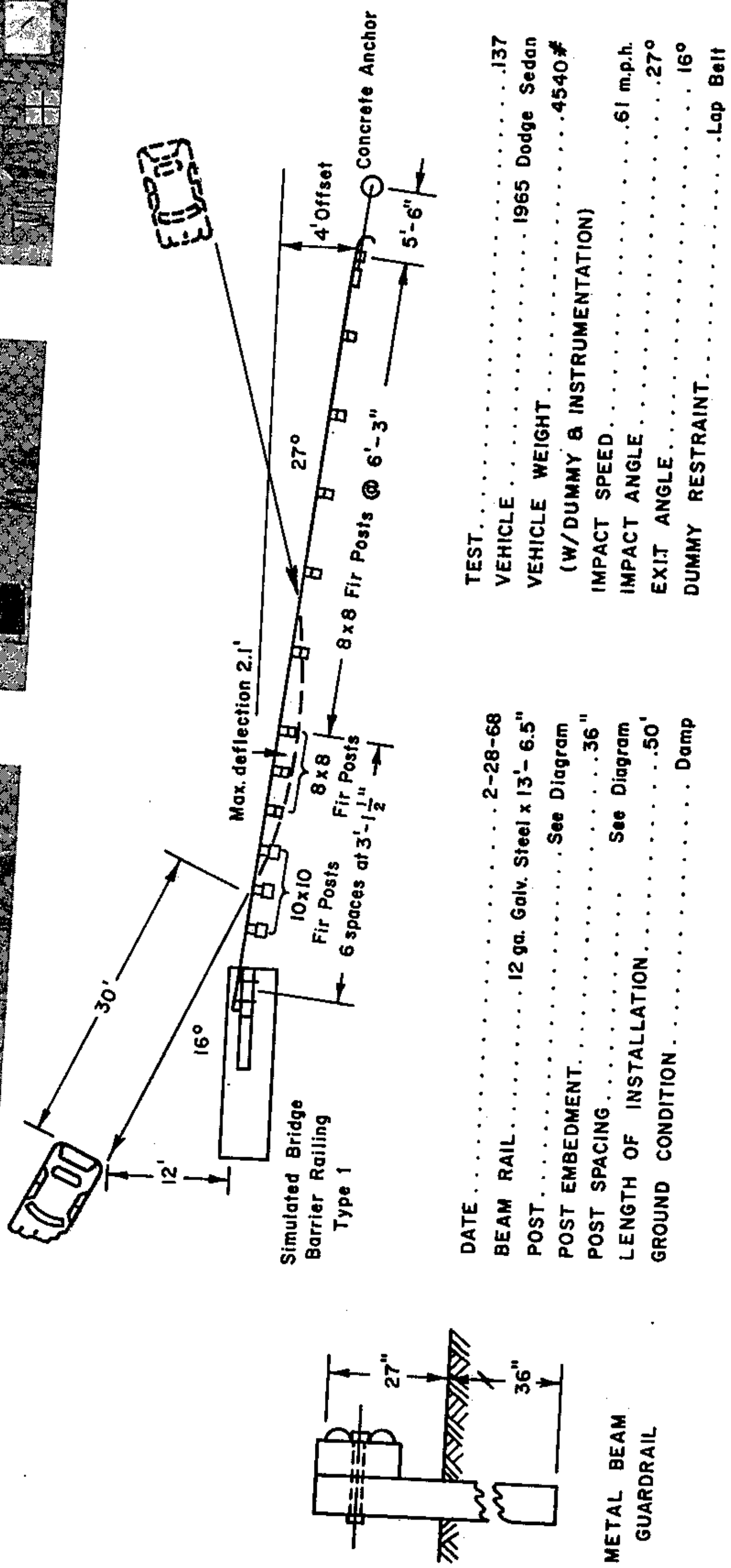
TEST 137 PLATE G

Impact

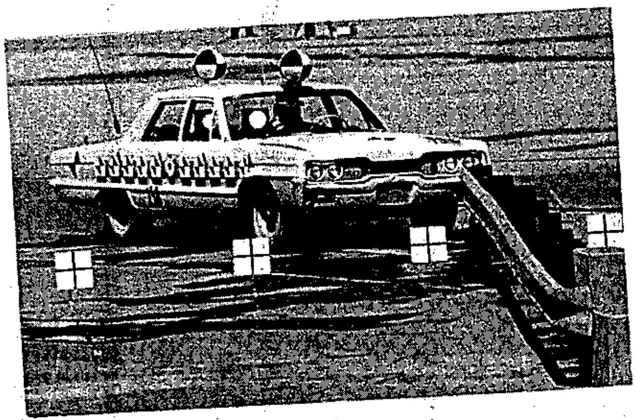
I + 0.15 Sec

I + 0.25 Sec

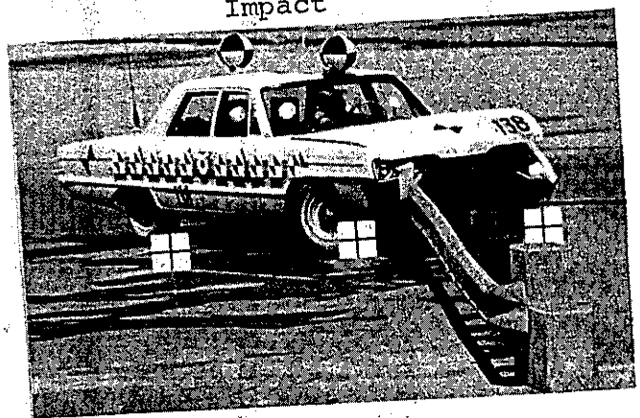
I + 0.50 Sec



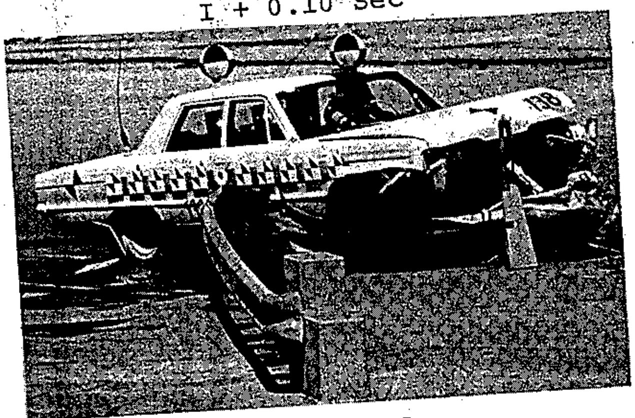
TEST 138 PLATE H



Impact

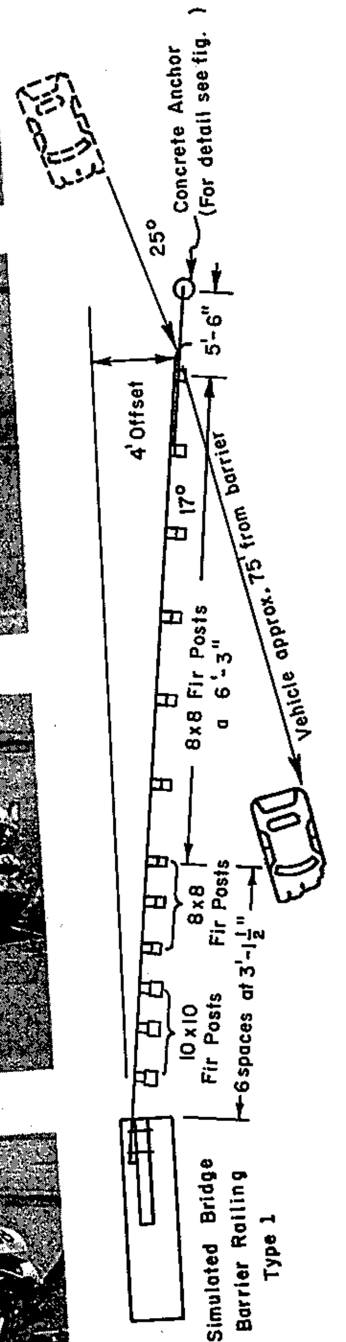


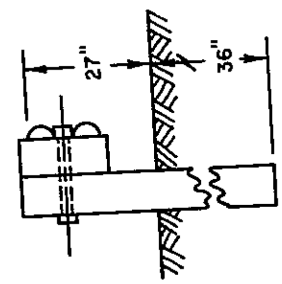
I + 0.10 Sec



I + 0.50 Sec

I + 0.70 Sec



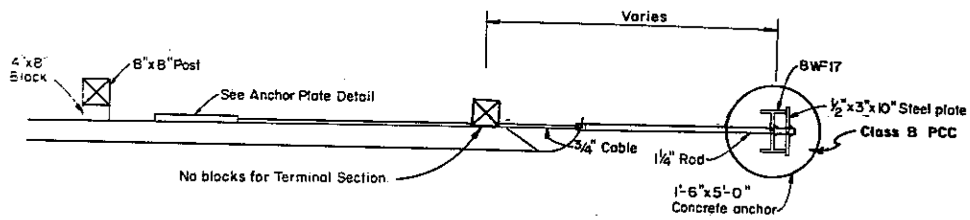




METAL BEAM GUARDRAIL

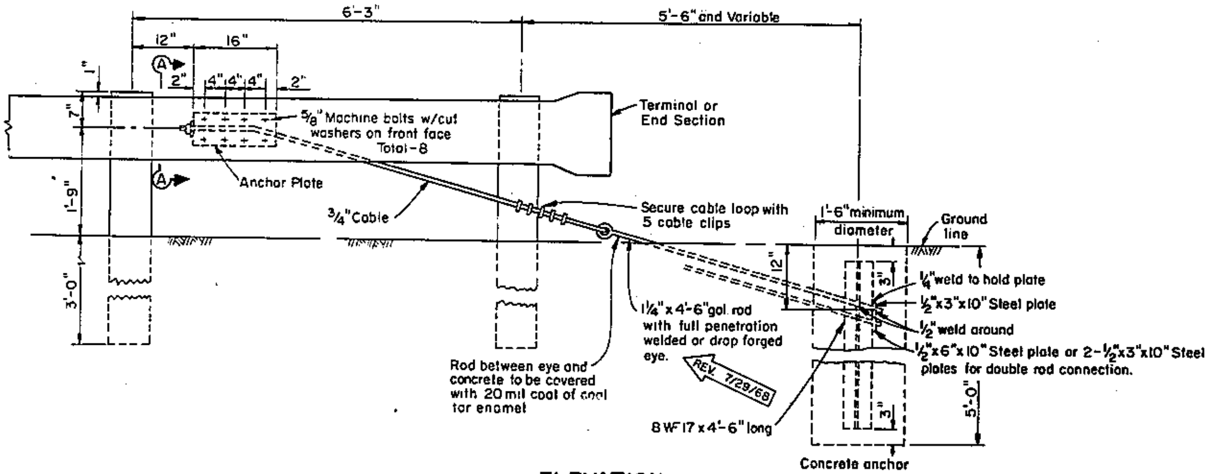
| | |
|---|---|
| TEST NO. | 138 |
| VEHICLE | 1966 Dodge Sedan |
| VEHICLE WEIGHT (W/DUMMY & INSTRUMENTATION) | 4670# |
| IMPACT SPEED | 61 m.p.h. |
| IMPACT ANGLE | 25° |
| EXIT ANGLE | 17° |
| DUMMY RESTRAINT | Lap Belt |
| DATE | 5-2-68 |
| BEAM RAIL | 12 ga. Galv. Steel x 13'-6.5" |
| POST | See Diagram |
| POST EMBEDMENT | 36" |
| POST SPACING | See Diagram |
| LENGTH OF INSTALLATION | 50' |
| GROUND CONDITION | Dry |

**EXHIBIT 1**

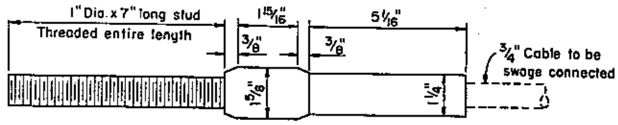
Note:
Cable to be parallel to guard rail for straight runs of rail. Cable may have angle point at anchor plate if guard rail is curved.



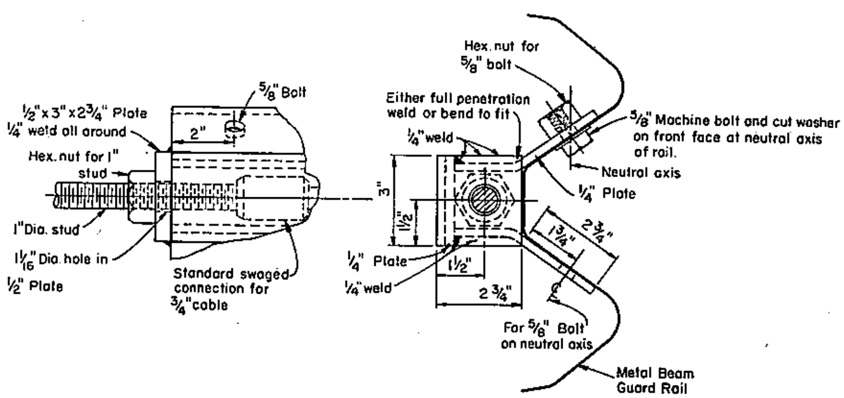

## PLAN VIEW




## ELEVATION




SWAGED FITTING AND STUD

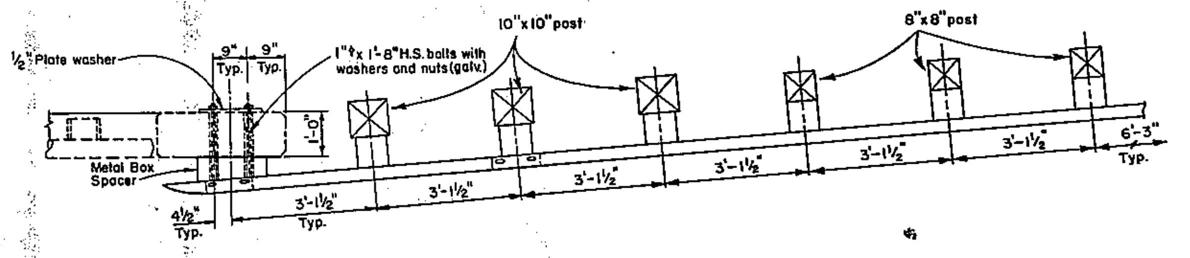



SECTION A-A

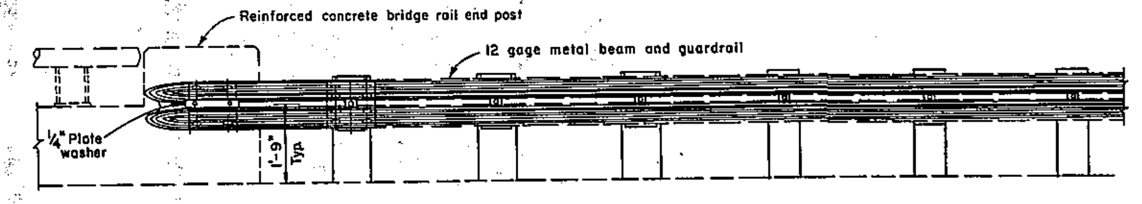
ANCHOR PLATE DETAILS

## CABLE END ANCHOR DETAILS

EXHIBIT 2




PLAN VIEW




ELEVATION

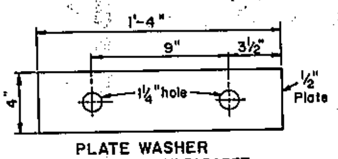



PLATE WASHER
FOR BACKSIDE OF PARAPET

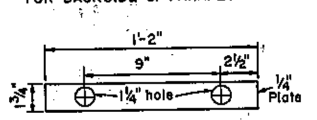
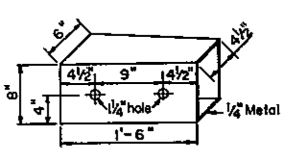



PLATE WASHER
FOR GUARD RAIL

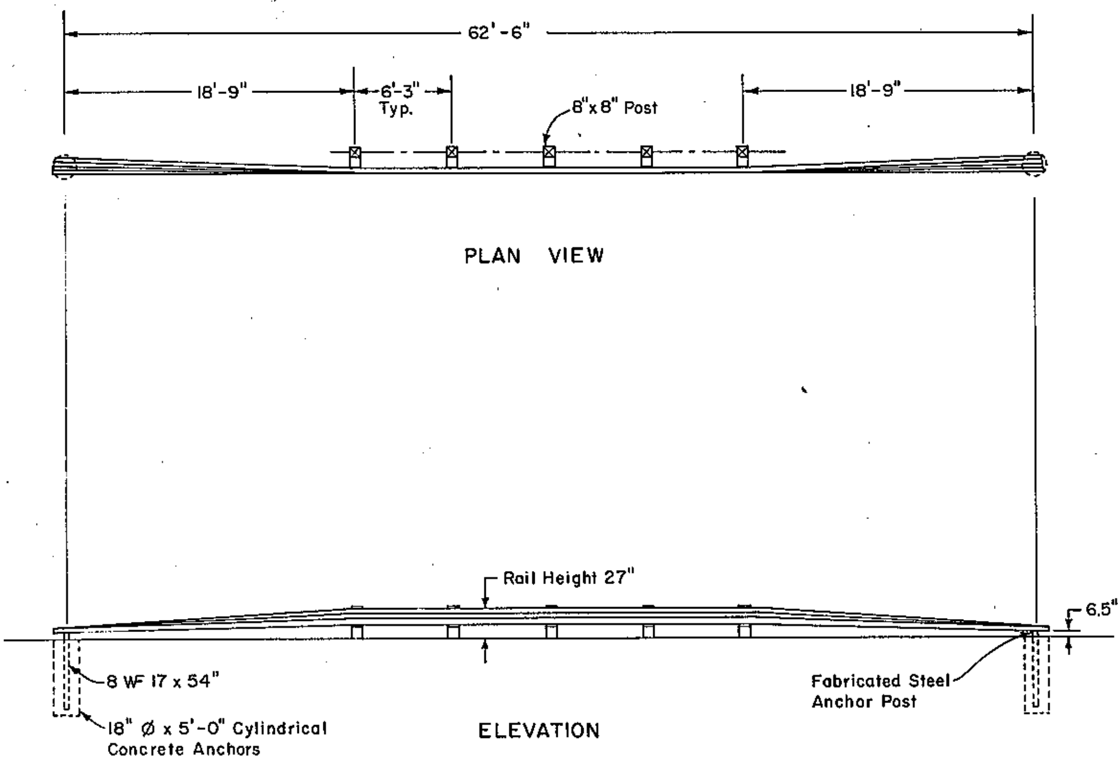


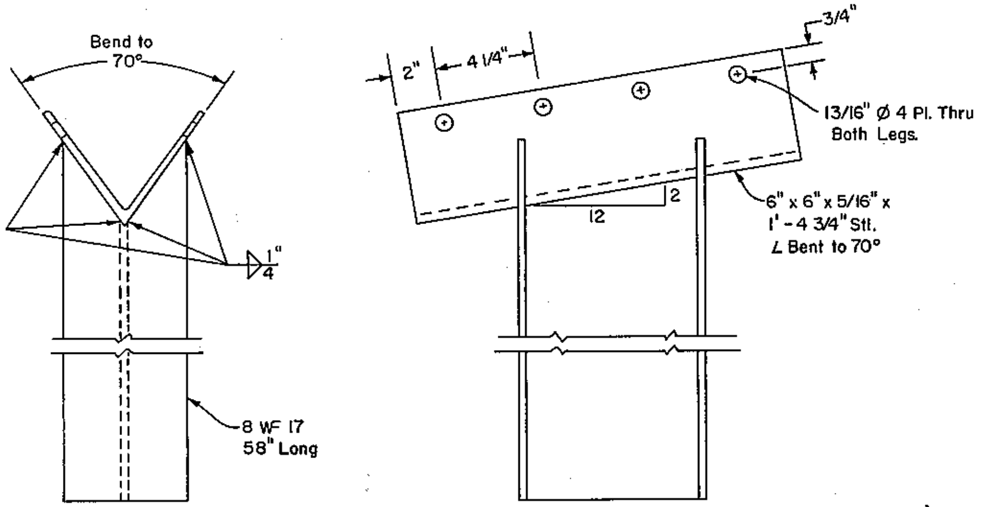

METAL BOX SPACER

When metal box spacer is installed, place 1¼"x5" and 1¼"x4" pipe spacers on 1" bolts passing through interior of box.

## GUARDRAIL CONNECTION DETAILS AT CONCRETE BRIDGE ABUTMENT

EXHIBIT 3

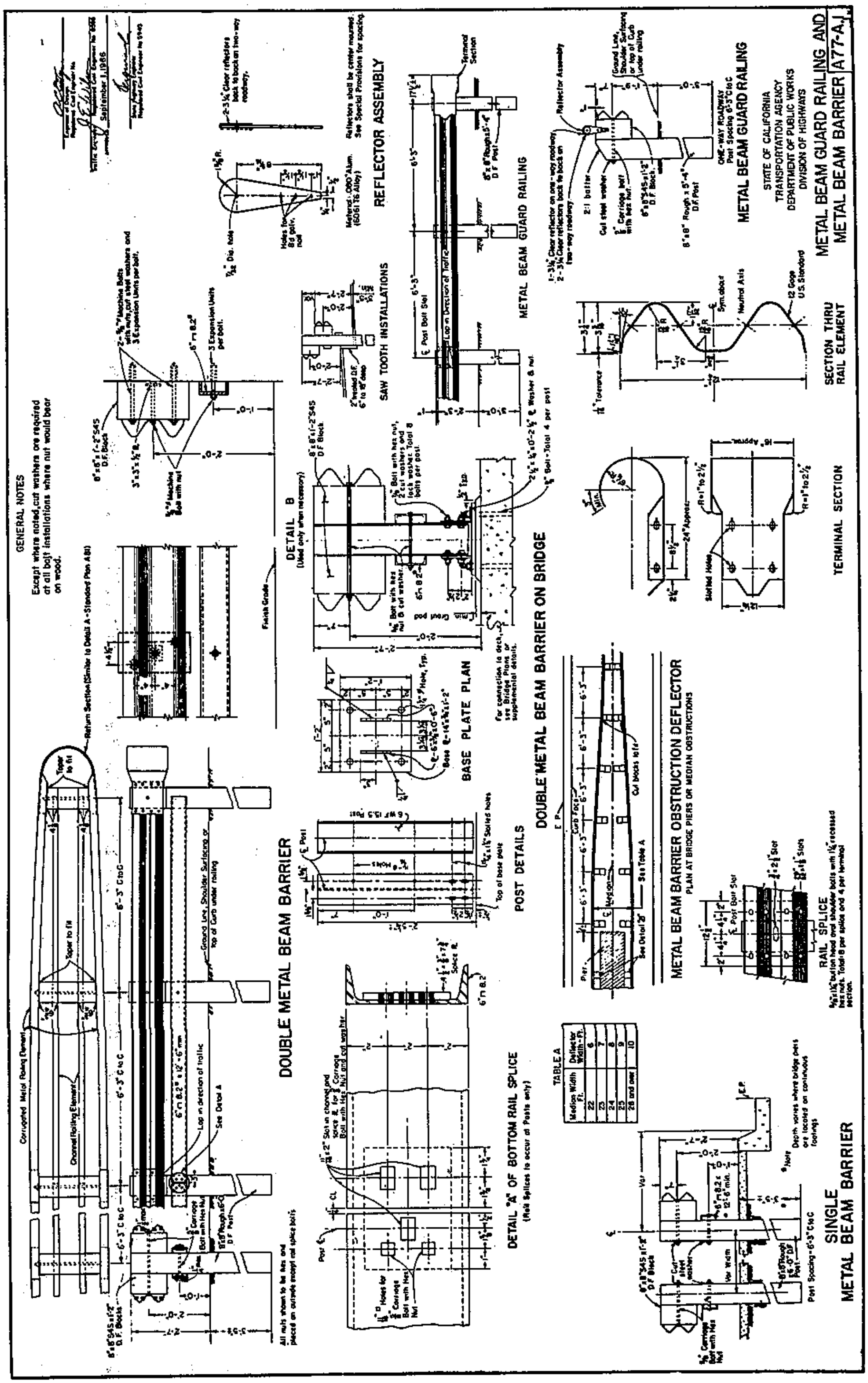



DETAIL - FABRICATED STEEL ANCHOR POST (Matl. Req. ASTM Desig. A-36)

"TEXAS TWIST" GUARDRAIL ANCHOR

EXHIBIT 4




1965 STANDARD PLAN

METAL BEAM GUARDRAILING AND METAL BEAM BARRIER